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COMMENTARY AND DISCUSSION ARTICLE

Analysis of the link between a definition of sustainability and the life cycle methodologies

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Abstract
Purpose It has been claimed that in order to assess the sustainability of products, a combination of the results from a life cycle assessment (LCA), social life cycle assessment (SLCA) and life cycle costing (LCC) is needed. Despite the frequent reference to this claim in the literature, very little explicit analysis of the claim has been made. The purpose of this article is to analyse this claim.
Methods An interpretation of the goals of sustainability, as outlined in the report *Our Common Future* (WCED 1987), which is the basis for most literature on sustainability assessment in the LCA community, is presented and detailed to a level enabling an analysis of the relation to the impact categories at midpoint level considered in life cycle (LC) methodologies.
Results The interpretation of the definition of sustainability as outlined in *Our Common Future* (WCED 1987) suggests that the assessment of a product's sustainability is about addressing the extent to which product life cycles affect poverty levels among the current generation, as well as changes in the level of natural, human and produced and social capital available for the future population. It is shown that the extent to which product life cycles affect poverty to some extent is covered by impact categories included in existing SLCA approaches. It is also found that the extent to which product life cycles affect natural capital is well covered by LCA, and human capital is covered by both LCA and SLCA but in different ways. Produced capital is not to any large extent considered in any of the LC methodologies. Furthermore, because of the present level of knowledge about what creates and destroys social capital, it is difficult to assess how it relates to the LC methodologies. It is also found that the LCC is only relevant in the context of a life cycle sustainability assessment (LCSA) if focusing on the monetary gains or losses for the poor. Yet, this is an aspect which is already considered in several SLCA approaches.
Conclusions The current consensus that LCSA can be performed through combining the results from an SLCA, LCA and LCC is only partially supported in this article: The LCSA should include both an LCA and an SLCA, which should be expanded to better cover how product life cycles affect poverty and produced capital. The LCC may be included if it has as a focus to asses income gains for the poor.

Keywords Capital theory · LCA · LCC · Life cycle sustainability assessment · LCSA · Poverty · SLCA · Sustainability · Sustainable development

1 Introduction

In the life cycle assessment (LCA) community, much attention has recently been devoted to the development of life cycle sustainability assessments (LCSA) (Finkbeiner et al. 2010; Halog and Manik 2011; Heijungs et al. 2009, 2012; Klöpffer 2003, 2008; Traverso et al. 2012; Wood and Hertwich 2012; Zamagni 2012). To our understanding, the goal of LCSA is in line with the goals of other life cycle (LC) methodologies to assess to what extent one product, service, technology, system or parts hereof (termed product for the remainder of this article) is better than another product in providing a certain service seen over the product's entire life cycle with regards to a certain goal, in this case the advancement of sustainability or

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sustainable development.[1] The assessment of the extent to which a product advances sustainability or the opposite will here be termed the assessment of 'a product's sustainability'.

In the above-mentioned publications, sustainability is defined (if defined at all) as in the so-called Brundtland report (WCED 1987) (termed the Brundtland definition in the remainder of this article). The approach for assessing a product's sustainability has in all publications been to combine the three LC methodologies: LCA, social LCA (SLCA) and life cycle costing (LCC), in the following way: LCSA = LCA + LCC + SLCA (Klöpffer 2008).

In existing publications, the claim expressed in the formula has only been discussed very shortly in Jørgensen et al. (2010) and in Klöpffer and Ciroth (2011). Apart from these rather short communications, no explicit analysis has been presented of the claim that a product's sustainability (defined as above) can be performed through summing the results from these three LC methodologies.

The purpose of this article is to analyse to what extent these LC methodologies can be used to assess a product's sustainability, when defining sustainability as in the Brundtland definition.

As the purpose of this article is to cover the assessment of sustainability in its entirety, it will cover many different areas. The analysis will therefore in many cases only be able to present a rough sketch rather than providing details on many of the concepts included in this article.

The approach for performing this analysis of the extent to which the LC methodologies can be used to assess a product's sustainability is to detail what is to be achieved by sustainability to an extent which allows for a direct comparison to the impact categories at midpoint level included in the LC methodologies.[2] The compatibility between this breakdown of the goals of sustainability, as defined here, and the impact categories will then indicate the extent to which the LC methodologies can be used to assess a product's sustainability.

In more detail, this will include an interpretation of the goals of the Brundtland definition of sustainability, which will primarily be presented in Section 2. On the basis of poverty research and economic theory, these goals will be further elaborated in Section 3 in order to establish some relative concrete measures of what needs to be maintained or enhanced in order to promote the Brundtland definition of sustainability as interpreted in this article. Finally, in Section 4, the measures outlined in Section 3 will be compared with the impact categories included in the LC methodologies in order to establish the extent to which the LC methodologies can be used to assess a product's sustainability.

2 An interpretation of the goals of the Brundtland definition of sustainability

As noted above, when defining sustainability, existing LCSA approaches adopt the Brundtland definition, and despite the numerous other definitions of sustainability (e.g., Pezzey 1992), this analysis will, because the unanimity within the LCSA community equally, use the Brundtland definition of sustainability as a point of departure for our analysis.

The Brundtland definition states that sustainable development is 'development that meets the needs of the present without compromising the ability of future generations to meet their own needs' (WCED 1987).

The definition opens up for several interpretations. We will, in the following, give our interpretation of its goal, where the guiding principle has been to be as faithful as possible to the overall message in the Brundtland report as we see it, but at the same time aim for simplicity and follow common understandings in the LCA/LCSA community.

First of all, we interpret sustainability as given in the Brundtland report to refer to two juxtaposed goals, namely to meet the needs of the present and to maintain the ability of future generations to meet their own needs. According to this, the role of an LCSA is to assess the extent to which a product life cycle affects either of the two goals: the meeting of needs of the present generation or the ability of future generation to meet their needs.

In relation to the second goal, an additional interpretation needed is what 'level' of abilities to meet needs future generations should have. The definition seems to point to some 'reference level' of ability to meet needs which the meeting of needs in the present should not affect. Where this reference level should be set is unclear. Our interpretation which we find to be in line with the Brundtland report is based on the idea of equity. The demand for equity both within current—intra-generational equity—and also equity among current and future generations—inter-generational equity—seems to be a dominant theme of the Brundtland report. Using this interpretation, this implies that the second goal can simply be understood as giving future generations the same possibilities as the current generation has had. The

[1] We will use the terms 'sustainability' and 'sustainable development' interchangeably. As outlined in Waas et al. (2011), the terms are in some cases used with different connotations. It is, for example, mentioned that some scholars assert that sustainable development is primarily about economic development, whereas sustainability gives priority to the environment. Others argue that the difference rather is that sustainable development should be seen as the process or journey to achieving sustainability (Reid 1995). However, in this context, where the goal is not to scrutinize the terms sustainability and sustainable development, it seems of less importance to distinguish between them.

[2] It may be argued that LCC does not include impact categories in the same way as LCA and SLCA. However, here, the impact category considered in LCC is taken to be the monetary costs or benefits to a defined stakeholder.

understanding is thus that given these possibilities, future generations will be free to pursue the same level of need satisfaction as we have in the current generation. A useful concept for understanding how the possibilities of future generations can be affected is the concept of 'capital' from economic theory. According to Costanza et al. (1997), capital can be understood as anything that '…generates, either autonomously or in conjunction with services from other capital stocks, a flow of services…to enhance the welfare of humans'. To this, it should be noted that in the Brundtland definition, the focus is on needs, rather than 'welfare'; however, we will here consider this as an acceptable difference. Thus, according to this, to give the future generations the same possibilities we have had, the stocks of capital need to be maintained.

Another important aspect regarding the second goal is how to understand the term 'future generations'. Do future generations start to 'arrive' in, e.g. 20 years from now, or should we understand future generations as 'arriving' constantly? Which of these positions is chosen will affect the LCSA, as for example acute impacts from the product life cycle will not be relevant for future generations if the perspective is a 20-year horizon, whereas they will be relevant if the horizon is simply the next instance. Our interpretation of this is that since generations do not arrive as discrete events but rather as a continuous event, setting up artificial generation boundaries will not be meaningful for the individual who will be affected if the ability to meet needs in the life time of the individual is depressed. Future generations will therefore here simply be understood as the world's population living in the future (both near and long term).

Another very central interpretation relate to the term 'needs' used in the Brundtland definition. Does the definition relate to all or only some needs? In the Brundtland report, it is stated that the term needs are: '… in particular the essential needs of the world's poor, to which overriding priority should be given' (WCED 1987). The main focus in the Brundtland report is therefore not on all needs, but rather on the essential needs of the ones who do not have the possibilities to meeting these essential needs by own means—i.e. the poor. As this is the main focus of the Brundtland definition of sustainability, and to keep the interpretation as simple as possible, our understanding will be that needs should be understood only as the essential needs of the poor. A further interpretation then relate to how to understand what it means to meet the essential needs of the poor. Several different interpretations of this could be given. One could be that the meeting of essential needs of the poor is simply a question of 'here-and-now' need satisfaction. However, even though that in some cases, here-and-now need satisfaction may be of essential importance, for example in the case of famine, a focus merely on need satisfaction may seem somewhat short sighted as the actual causes for the lack of abilities of the poor for meeting needs will probably not be affected by this strategy. In line with this argument, it could be claimed that emphasis should be put on the word 'development' in the sustainable development concept, i.e. progress towards the goal, and that this goal should be that the poor should be able to meet their essential needs through own means; in other words, a development towards alleviating poverty. Thus, through this interpretation, meeting the essential needs of the present poor will be understood as alleviating poverty.

As is evident from above, several interpretations of the Brundtland definition have been made here to reach these conclusions. We have made these interpretations on the basis of the guiding principles outlined above, but still several other interpretations are possible which could have lead to other conclusions than the one presented here. However, if we accept the interpretations of the Brundtland definition of sustainability presented here, the LCSA is to assess the extent to which products throughout their life cycle affect:

1. Poverty in the present generation
2. Maintaining the stock of capital for people living in the near and long-term future

Thus, when assessing a product's sustainability, according to the interpretation above, we need to assess the extent to which a product affect these two goals—nothing more, nothing less. The extent to which the LC methodologies assess how a product life cycle affects these goals will determine the validity of the link between the LC methodologies and the definition of sustainability.

The interpretation of the goal of the Brundtland definition of sustainability is therefore very important for the outcome of the study, and as the interpretation by definition is debatable and not an incontestable truth, it seems relevant to establish the extent to which this interpretation of the goal of the Brundtland definition corresponds with other interpretations given in literature. This will be analysed in the following.

An enormous amount of literature has been written about the Brundtland definition of sustainable development. When going through (parts of) this literature in the making of this article, the interpretations of the Brundtland definition are in many cases from a first glance different from what has been presented here. The probably most common interpretation of the Brundtland definition is the reference to the 'three dimensions' of sustainability, namely environment, society and economy, as also discussed in the Brundtland report (WCED 1987) and as stated more explicitly in, e.g. Giddings et al. (2002). Here, the goal of sustainability is often seen as bringing the three dimensions together in a balanced way, reconciling the conflicts between environmental protection, social equity and economic growth. At a first glance, this interpretation seems very different from the interpretation made above, but as will briefly be discussed in

Section 5, the apparent differences may be very limited depending on how and for whom these goals of environmental protection, social equity and economic growth are to relate.

Another difference between the interpretation of the Brundtland definition given above and what is found in literature is that the interpretation given above is made on the basis of the stated definition in the Brundtland report (including a few statements from the report itself), whereas other interpretations are based on a lingual analysis of the two words included: 'sustainable' and development. Lélé (1991) presents several different interpretations based on lingual analysis, of which several differ significantly from the interpretation above. One example is that sustainable development according to this lingual analysis can be understood as merely a question of ensuring continued economic growth. Yet, as pointed out by Lélé (1991), interpretations like these are not considered mainstream in the scientific debate and should probably be seen as attempts to 'green (or sustainability) wash' decisions taken on company or national level (Lélé 1991). Lélé (1991) also argues that the lingual analysis of sustainable development indicates that the term may be meaningful if it relates to the meeting of basic needs, while maintaining a large concern for the ecological and social basis for human life. If meeting basic needs is understood as alleviating poverty, as understood here, and the maintenance of the ecological and social basis for human life is understood as maintaining capital, this interpretation by Lélé (1991) seems to be reasonably close to the interpretation made above.

If going from these interpretations of the entire Brundtland definition and move to the specific interpretations made above, several similarities and differences can be found when comparing to literature. One example is that whereas it is commonly agreed that the Brundtland definition includes two goals, as also outlined above, others have argued that the goal relating to improvement of the conditions for the poor should merely be seen as a means rather than a goal in itself (see discussions in Lafferty and Langhelle 1999). But as argued by Lafferty and Langhelle (1999), this position has been severely criticised and should probably not be seen as a mainstream interpretation.

Another very common interpretation of the Brundtland definition is that it combines the concern for both the need for development for the world's poor and the concern for environmental protection (Føllesdal 1999). In our interpretation of the Brundtland definition, we do consider the goal of alleviating poverty but rather than stating the protection of the environment, we state the conservation of capital as a way for enabling future generations to meet their needs. As will be discussed in Section 3.2, the concept of capital refers to different types of capital among which natural capital is one. When arguing for the need for maintaining capital, it relates also to environmental protection but is broader as it also includes other types of capital which according to capital theory will equally affect the possibility for meeting needs. We believe therefore that the maintenance of capital rather than the more narrow focus on environmental protection gives a more covering theory of how present actions can affect future people in meeting their needs.

A final difference which can be found in literature relate to the interpretation of needs. From above, we interpret the demand for meeting the needs of the present as a demand for alleviating poverty. Others have interpreted the concept of needs much more literally. Håland (1999) is an example of this. But whether the concepts of basic needs and poverty differ in significant ways is not fully clear. For example, as a kind of definition on poverty, Max-Need (1992) states that 'any fundamental human need that is not adequately satisfied, reveals a human poverty', indicating a close link between the concept of (basic/fundamental) needs and poverty. As the two concepts seem to be closely related, the actual difference in focus that this creates for the development of LCSA is therefore believed to be minimal.

Even though this analysis only presents a small amount of the literature written about the Brundtland definition, it seems reasonable to state that the interpretation of the goal of the Brundtland definition given above is within rather mainstream views. However, at the same time, it was also shown that smaller differences between our interpretation and literature can be found, for example in the focus on poverty over basic needs and in the focus on conserving all capital, and not only natural capital to enable future generations in meeting their needs.

3 Operationalisation of the goals of sustainability

Having established an interpretation of the goals of sustainability, we will in the following continue the analysis by outlining in more detail what needs to be maintained or promoted in order to alleviate poverty and to maintain capital.

3.1 The concept of poverty

In the following, we will start by outlining a theory of what poverty is, which will be followed by a more concrete outline of what needs to be promoted or enhanced to alleviate poverty.

In the Human Development Report from 1997 (United Nations 1997), it is stated that: 'It is in the deprivation of the lives that people can lead that poverty manifest itself'. As such, this overall understanding is in line with the theoretical framework of a central figure in the attempt to capture the concept of poverty, namely Amartya Sen and his work on the

'capabilities approach' (Sen 1985, 1992). The 'capability approach' understands poverty in terms of the freedom that a person enjoys in terms of the person's 'functionings'. The functionings deal with what a person can ultimately do indicating the freedom that a person enjoys. The lower the freedom, the higher the poverty. These functionings may, for example relate to access to education or health care and can in many cases be approximated by attributes such as literacy, life expectancy, etc. Also, income can be used as an approximation of functionings based on the assumption that, in principle, an individual with income above a certain poverty line is thought to possess the potential purchasing power to acquire the bundle of attributes yielding a level of well-being sufficient to function (Thorbecke 2008). In the least developed countries, the question of what poverty is, is therefore most often considered to be the inability to afford a minimum standard of goods necessary for physical sustenance, such as food, clothing, shelter and medicine, commonly set to US$1 a day, roughly corresponding to the means necessary to buy this (Niemietz 2011). However, a central problem relating to this measurement is that income as an indicator for poverty has difficulties in reflecting other functionings better expressed in terms of life expectancy, literacy, the provision of public goods and freedom and security (Thorbecke 2008). Multidimensional poverty measures not only focusing on income have therefore been developed. An example of a multidimensional understanding of poverty adopted by the UN World Summit for Social Development (WSSD 1995) is given below:

> Poverty has various manifestations, including lack of income and productive resources sufficient to ensure sustainable livelihoods; hunger and malnutrition; ill health; limited or lack of access to education and other basic services; increased morbidity and mortality from illness; homelessness and inadequate housing; unsafe environments; and social discrimination and exclusion.

It should be noted that other multidimensional measures can be found, but they in general include many similar measures. However, if these multidimensional measures outlined here can be accepted to reflect the dimensions of poverty, what needs to be analysed here is whether there is compatibility between impact categories in LC methodologies and these measures. This will be analysed in Section 4 after a discussion about the concept of capital.

3.2 The concept of capital

As already noted above in Section 2, capital can be understood as anything which generates, either autonomously or in conjunction with services from other capital stocks, a flow of services to enhance the welfare of humans (Costanza et al. 1997). Capital is in several regards a contested concept. One issue is that whereas it is clear that there are several different types of capital which may create a flow of services to enhance human welfare, it is not entirely clear which types exist. The World Bank (1997) suggests that the categories of capital include natural, produced, human and social capital. This categorisation has been used in the following as we find it provides a consistent framework for understanding the different types of capital; however, it should be noted that several other types of capital have been suggested, such as cultural capital (Berkes and Folke 1997) and moral and ethical capital (Stern 1997).

Another issue in the discussion of the concept of capital is presented by Stern (1997) who writes that embedded in capital theory is the idea that capital to some extent can be aggregated using monetary valuation, implying some level of substitutability between capital—either between or within different types of capital. Stern (1997) questions this possibility, hereby implying that to ensure sustainability minimum stocks of each type of all capitals should be maintained, which, as Stern (1997) notes, goes against the essence of capital theory. Even though this may question the idea of commensurability of different types of capital, which may also be important concern in an LCSA attempting to give an aggregated sustainability score for a product, what is of main concern here is primarily to have a covering framework for what needs to be maintained in order to give future generations the same possibility for meeting their needs as the current generation has had. To this end, we see capital theory as a useful concept. In the following, the four types of capital, namely natural, human, social and produced capital, will be presented with regards to what services the capital provides enhancing the welfare of humans and with regards to what needs to be protected in order to maintain or enhance the type of capital.

With regards to natural capital, the Millennium Ecosystem Assessment (2005) categorises four different types of services provided by natural or semi-natural ecosystems, including the following:

1. Support services, which relate to, for example nutrient cycling, soil formation and primary production
2. Provision services, for example relating to the provisioning of food, fresh water, wood and fuel
3. Regulation services, e.g. climate and flood regulation and water purification
4. Cultural services relating to the provision of opportunities for reflection, spiritual enrichment, cognitive development, recreation and aesthetic experience given by nature

In the Millennium Ecosystem Assessment (2005), the state of ecosystems to provide these services is addressed and concludes that a series of drivers may threaten these ecosystems. These drivers affect ecosystems directly and

indirectly. The most important drivers of more indirect character include issues like population change, change in economic activity, sociopolitical factors, cultural factors and technological change. The most important drivers of more direct impact on the services provided by ecosystems are stated to be land use change and physical modification of rivers or water withdrawal from rivers; overexploitation of natural resources; invasive alien species; pollution, such as emissions of N and P leading to eutrophication; and climate change (Millennium Ecosystem Assessment 2005). Thus, affecting these direct or indirect drivers will affect ecosystem services. An LCSA having as a goal to assess how product life cycles affect, among others, natural capital therefore needs to consider how product life cycles affect these drivers.

Contrary to natural capital which resides in nature and thus outside humans, human capital is capital which resides in the individual. Human capital has been understood as anything which affects the individual's capacities for enhancing welfare (Schultz 1961). Most notably, this has been considered to be as follows:

1. Education and training, understood as for example; on-the-job training; formally organised education at the elementary, secondary and higher levels; and other study programmes
2. Health understood as life expectancy, strength and stamina and the vigour and vitality of people
3. Willingness to adapt, e.g. the migration of individuals or families to meet changes in the job market (Schultz 1961)

Thus, human capital may be affected by affecting any of these three aspects.

Social capital is a contested concept, and different definitions circulate. However, according to one of the founding fathers of social capital, Coleman (1988), it has to do with the resources embedded in a social relation or network. Social capital is thereby not a possession of the individual but embedded in the relations between individuals.

Social capital can be divided into a structural (networks) and an attitudinal (trust and norms of reciprocity) component (Hooghe and Stolle 2003). Social capital needs both, since without the structural element, there is no network to embed resources in, and without the attitudinal component, the structure does not represent a resource. Social capital enhances welfare by allowing sharing of information, coordination of activities and collective decision-making (World Bank 1997). However, as it has been pointed out, some networks may from a societal perspective be counterproductive in relation to the resources embedded in them, since many organisations are built on distrust rather than trust, for example religious, political, ethnic or nationalist organisations, which base their existence in part on establishing exclusion, hostility and distrust toward members of competing organisations/networks (Kumlin and Rothstein 2004, Hooghe and Stolle 2003). Because of this complexity, the understanding of what is needed in order to protect or enhance social capital, which is what is of relevance here, is underexplored (Hooghe and Stolle 2003). Research suggests that the creation or destruction of social capital is a result of a complex interplay between individual and societal initiatives (Hooghe and Stolle 2003). This indicates that, at least with the present level of knowledge, outlining how certain events related to product life cycles will result in the creation or destruction of a certain amount of 'social capital', currently seem infeasible.

Produced capital can be understood as physical assets facilitating a production which is man-made. In this way, produced capital stands in contrast to the other types of capital above in that natural capital is not man-made and in that human and social capital are not physical, but resides in individuals or in groups. Produced capital is not used up immediately in the process of production of welfare but may depreciate over time in the production process. Examples of produced capital may be various types of infrastructure such as machinery, buildings and computers (Samuelson and Nordhaus 2006). Thus, produced capital may be affected through affecting the productivity of infrastructure.

4 Linking poverty and stock of capital to LC methodologies

Having given a brief introduction to the concepts of poverty and the different capitals and outlined the measures by which poverty and capital may be affected, what will be analysed below is how impact categories at the midpoint level in the LC methodologies relate to these measures. We will address each of the three LC methodologies in turn.

As was evident in the discussion about natural capital, there is a large overlap between what is assessed in LCA and the direct drivers impacting the ability of ecosystems to deliver services. This includes the use of non-renewable and renewable resources (including land use and water use), global warming and eutrophication (EC 2010). Whether this indicates that life cycle impact assessment (LCIA), which most often includes several other impacts categories than outlined here (EC 2010), is too broad will not be discussed further here, but it should be noted that the drivers outlined above are only the ones considered most important drivers (Millennium Ecosystem Assessment 2005), indicating that other drivers may be added to this list, potentially giving a more complete degree of compatibility to impact categories included in LCA.

It should also be noted that LCA only relates to the direct drivers affecting ecosystems. The indirect drivers, like population change, change in economic activity or changes in culture, are not considered in LCA probably because they are not considered directly affected by the product perspective

maintained in LCA. Based on this, it seems that the drivers affecting ecosystems which may be affected by the product life cycle are to a very large extent already included in the LCA methodology.

Furthermore, LCA also includes impacts on human capital as it includes impacts on human health, for example through the assessment of toxic impacts on human health. However, there may be a difference in how this impact is interpreted. In LCA, the focus is merely to assess changes in health in the population in general, whereas the relevance of the heath impacts in relation to human capital will vary depending on its influence on welfare.

SLCA is less established than LCA, and it is therefore more difficult to establish as firmly what SLCA includes and do not include. However, if existing SLCA approaches are considered, they seem to relate to both the concept of poverty and that of capital. In relation to poverty, several SLCA approaches have, for example, addressed the question of job creation and fair wages as well as impacts on workers' health both in terms of fatal and non-fatal accidents, education of workers and incidences of discrimination against workers or applicants (Jørgensen et al. 2008). In this way, SLCA approaches include many of the issues considered to be comprised in the concept of poverty, but still the overlap is not complete. For example, no SLCA approaches to our knowledge address issues like local crime levels, adequate housing or general access to education or other basic societal services.

When it comes to human capital, SLCA approaches also very frequently focus on both health impacts of workers and to some extent product users as well as education of workers (Jørgensen et al. 2008). In relation to produced capital, it seems that this is generally not considered in SLCA approaches; however, few exceptions exist. For example, Spillemaeckers et al. (2004) include support from the company included in the product life cycle for infrastructure projects and Schmidt et al. (2004) also indicate the relevance of including produced capital in SLCA.

While SLCA in some respects is too narrow in its scope, it may, at least in principle, be too broad in others. For example, SLCA in general assesses social impacts on any stakeholder affected by the product life cycle, but as LCSA is only to relate to poverty alleviation and maintenance of capital, measures only related to poverty alleviation should only be considered in relation to poor stakeholders. Thus, in principle, some distinction between poor and non-poor stakeholders should be made which would affect what to assess for what stakeholders. However, two issues need to be considered in this connection. First of all, there is to some extent an overlap between measures related to poverty alleviation and maintenance of capital. For example, the effect of product life cycles on education and health relates to both poverty and human capital, implying that, e.g. education and health issues should be considered for both poor and non-poor stakeholders (as product life cycles' impacts on human capital should be assessed for all stakeholders, not only the poor). In order to make the distinction between what to asses for what stakeholders, there is therefore a need for having a very clear overview of which measures relate to poverty alleviation and which relate to maintenance of capital and only make the distinction where there is no overlap. Secondly, in practice identifying which stakeholders are, in fact, poor or in danger of becoming poor may be rather difficult information to collect. To what extent SLCA therefore is too broad and should be narrowed for some stakeholders, and whether this is feasible in practice remains to be seen in future studies.

LCC, which has as a goal to assess the monetary costs or gains for certain stakeholders, is somewhat harder to relate to either poverty alleviation or maintenance of capital. However, under some assumptions, LCC can be seen to assess issues of relevance for poverty. If what is considered in the LCC is only income generation for the poor, then as income generation is seen as one component of poverty alleviation, the LCC with this focus could be used to express a dimension of poverty.

5 Discussion

The above analysis indicates that the current consensus that LCSA can be performed through combining the results from an SLCA, LCA and LCC can only partially be supported: the LCA and the SLCA seem to cover a broad range of the issues relevant for achieving a sustainable development, as defined here, including how product life cycles affect poverty, natural capital and human capital, but still the LC methodologies were not able to capture the entire breadth of the concept of sustainability, probably most noticeable in relation to some aspects of poverty alleviation and in relation to produced and social capital. One reason for this may be that the focus of the LC methodologies in some regards may simply be too narrow to capture the breadth of the concept of sustainability, but another very probable reason may also be that there is a limit to what the product life cycles in general affect. For example, as already stated above, product life cycles may probably not in a direct manner affect population or cultural changes even though these may be significant drivers for changes in natural capital. In this way, it may seem very relevant to establish a theory of how product life cycles affect their surroundings. In LCA, the theory of how products affect their surroundings seems to be that it is the sum of the tangible inputs and outputs from a product system, but when it comes to the area of SLCA, this attempt to include all possible interactions between product life cycles and people becomes problematic. A theory of how product life cycles in general affect their surroundings may be useful in setting the boundaries for what needs and what needs not to be considered in an SLCA focusing on assessing sustainability.

The analysis furthermore showed that the LCC may be 'squeezed' into the LCSA equation, if adopting a rather special scoping for the LCC, namely an assessment of the income generated for the poor. However, in general, it may be argued that what the LCC can provide in this context is already a topic considered in several SLCA approaches (Jørgensen et al. 2008) and the relevance of including LCC may therefore be questioned. In this way, this analysis adds further nuance to the conclusion reached in Jørgensen et al. (2010) where it was argued that only an LCA and SLCA were necessary in a sustainability assessment in contrast to the more common interpretation that all three LC methodologies are used, as outlined in Section 1.

To this, it should be noted that just because the role of LCC is questioned in LCSA based on the understanding of sustainability as presented here, this analysis does not reject the common interpretation of the three dimensions of sustainability, but simply the interpretation that the economic dimension can be addressed through an LCC. The economic dimension of sustainability may relate to the macro-economic conditions in a country which are very important in relation to poverty alleviation (Vylder 2002) or impacts on natural capital (Millennium Ecosystem Assessment 2005), and which also corresponds to the interpretation of what the economic dimension amounts to in the interpretation of sustainability made in Agenda 21 (United Nations 1993).

Also, it should be noted that by questioning the relevance of LCC in LCSA, this analysis does not claim that that LCC is irrelevant in general. An LCC assessment may provide highly useful information about the product life cycle for a decision-maker. However, in this connection, it should be mentioned that there at times seems to be a confusion of words: an LCC can tell something about the cost-effectiveness of a good and thereby the chances of a company producing the good to survive or, if using the literal sense of the word, whether a company is sustainable. The LCSA, as defined here, is focussing on assessing how product life cycles affect the meeting of the needs of the present and future generations, a goal which we term 'sustainable development' regardless of whether it makes sense from a literal perspective. The word sustainable can thus be used in both contexts but with two different meanings, which in many cases will not in any obvious way be related. The two uses of the word—the literal and the 'non-literal'—should thus be kept apart.

6 Conclusions and future research

In this analysis, it has been argued that the Brundtland definition of sustainable development can be seen as comprising two goals, namely alleviation of poverty and conservation of capital. Comparing these goals with what is assessed in the three LC methodologies, it was concluded that especially LCA and SLCA include impact categories at the midpoint level relating to many of the measures affecting both poverty and parts of the capital concept, namely natural and human capital. Produced capital is not to any large extent considered in any of the LC methodologies, and because of the limited present knowledge about what creates and destroys social capital, it is difficult to assess how it relates to the LC methodologies. It was also concluded that the LCC is only relevant in the context of an LCSA if focusing on the monetary gains or losses for the poor. Yet, this is an aspect which is already considered in several SLCA approaches.

This analysis therefore points to that due to these inabilities of current LC methodologies to capture the entire breath of the concept of sustainable development, it is not possible with existing LC methodologies to state an equation along the lines of Klöpffer (2008), outlined in Section 1. However, if SLCA is modified to better include the aspects of poverty alleviation and furthermore is expanded to cover issues related to produced capital (as aimed for by Schmidt et al. 2004), it can be stated that:

$$\mathrm{LCSA} = \mathrm{SLCA}_{\mathrm{modified}},\ \mathrm{LCA\ and\ LC}_{\mathrm{social\ capital}}$$

or

$$\mathrm{LCSA} = \mathrm{SLCA}_{\mathrm{modified}}, \mathrm{LCC}_{\mathrm{poor}}, \mathrm{LCA\ and\ LC}_{\mathrm{social\ capital}}$$

where $\mathrm{SLCA}_{\mathrm{modified}}$ is an SLCA expanded to cover issues related to poverty alleviation and produced capital, $\mathrm{LCC}_{\mathrm{poor}}$ is an LCC directed towards assessing income generation for the poor and $\mathrm{LC}_{\mathrm{social\ capital}}$ is a yet unknown life cycle methodology aiming at assessing the impacts from product life cycles on social capital. Both equations may do, but if the first is used, income generation for the poor should be included in the SLCA. In the second equation, this aspect should only be handled in the LCC and omitted from the SLCA to avoid double counting.

As emphasised in Section 1, this article has only given a rough sketch of the link between one definition of sustainability and the LC methodologies. Many important elements are still to be clarified. Some of these elements can be clarified though decisions and agreement in the LCSA community and are therefore definitional in character, whereas the clarification of others rests on the results of future empirical work and will therefore depend on research.

The decisions that seem particularly important to handle in the LCSA community are first of all:

- Is sustainable development in the context of LCSA to be understood in line with the definition given in the Brundtland report (WCED 1987)?
- If this is the case, should the interpretation of the definition be as outlined in Section 2?

These questions are not research questions in the sense that there is no right or wrong definition of sustainability or only one justifiable interpretation of the definition, and these questions therefore to a large extent rest on the agreement of the LCSA community and with the wider scientific community dealing with sustainability science. However, without some agreement about these fundamental questions, the following empirical work rests on un-solid grounds.

If the definition of sustainability chosen here and the interpretation of the definition made in Section 2 can be accepted, the most important research tasks seem to be:

- Is the concept of capital fully captured through the combination of natural, human, social and produced capital?
- What creates and destroys social capital and how can product life cycles in general affect this?
- How do product life cycles in general affect in particular poverty and produced capital and what indicators could be used to capture this effect?
- How can an LCIA be developed which captures the impacts of product life cycles on natural capital?
- Can a comprehensive theory about the impacts from product life cycles on its surroundings be developed?

Besides, these issues there are of course still many still unresolved issues in both LCA and SLCA which will be equally important to resolve when it comes to LCSA as outlined here. The issues outlined above are only the decisions and research tasks which lie over and above what is relevant to address in LCA and SLCA.

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